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Fertilizer and sustainable intensification in Sub-Saharan Africa

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ABSTRACT

The paper investigates the important role of fertilizer to enhance sustainable intensification and food security in Sub-Saharan Africa (SSA) based on a multi-disciplinary literature review. The review starts with a macro-perspective taking population growth, economic development and climate change into account. This is complemented with a micro-perspective summarizing findings from comprehensive micro-data in selected African countries. Agronomic, environmental and economic profitability implications of fertilizer use are reviewed. The poor but efficient hypothesis is assessed in light of recent evidence in behavioral economics. Is low fertilizer use due to hard constraints farmers face or partly due to irrational behavior, and what are the policy implications? Two policy approaches, input subsidy and productive safety net programs, are reviewed and their potential roles to enhance sustainable intensification and nutrient use efficiency in SSA agriculture are discussed before I conclude.

1. Introduction

Africa was for decades the least developed continent where economic growth barely kept up with population growth. Agriculture was the dominant sector in most African countries and smallholder farming the main source of livelihood for the large rural majority. Agricultural production expanded through area expansion and yields were stagnant except for some pockets. The Green Revolution that was successful in Asia failed in Africa and adoption rates for improved varieties and fertilizer were low. As late as in Crawford et al. (2006), in their review for the World Bank, reported average fertilizer rates as low as 9 kg/ha in Sub-Saharan Africa, while disappearing fallows, high levels of deforestation, land degradation and nutrient depletion indicated non-sustainable land use. Eight years later, Sheahan and Barrett (2014, 2017) review the most recent Living Standard Measurement Survey data from six African countries, which revealed an extremely heterogeneous pattern of fertilizer use in these six countries. Economic growth has also picked up in many African countries and an economic transformation has started. Further production increase through area expansion is no longer feasible in an increasing number of countries, making land use intensification necessary to meet future food needs of a growing population (Chamberlin et al., 2014). The need to halt deforestation to reduce carbon emissions also creates pressures to stop agricultural expansion into woodlands and forested areas. Tilman et al. (2011) estimate that area expansion is associated with three times as high greenhouse gas emissions as area intensification to achieve the same production increase. Africa is the continent with the lowest cereal yields and lowest production intensity and where the population will increase the most (Mueller et al., 2012; Ray et al., 2013).

The overall objective of this paper is to provide an integrated macro-micro-environment review of the role of inorganic fertilizer in the process of transforming the agricultural sector in Sub-Saharan Africa (SSA) to meet future food security while facilitating sustainable intensification and minimizing environmental damages. More specifically, the paper aims to

a) Review micro data on fertilizer use and intensity of use in selected SSA countries.
b) Review important agronomic and environmental concerns and implications of heterogeneity in profitability and incentives to use fertilizer by farmers.
c) Assess whether the rational small farmer paradigm ('poor but efficient') is adequate to understand their behavior or needs to be complemented with other models which have different policy implications based on recent lessons from behavioral development economics.
d) Assess alternative controversial and potentially important policies used to promote sustainable intensification and food security in SSA.

2. Macro versus micro evidence on fertilizer use in SSA

Nitrogen is the most important nutrient that can enhance crop yields. Zhang et al. (2015) assess the central role of nitrogen (N) to facilitate sustainable intensification. While higher N use is necessary, it

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Table 1
Average inorganic fertilizer use per ha in selected SSA countries, total nutrients.
Sources: Reproduced from Sheahan and Barrett (2017, p. 15) based on LSMS-ISA data.

	% of cultiv. househ. using	Use (kg/ha) across all households		Use (kg/ha) across only fertilizer using households				
		Mean total, all households	Mean nutr.	Mean total	Mean N	Mean P	Mean K	Mean nutr.
Ethiopia	55.5	45	25.2	81	23	22.5	–	45.5
Malawi	77.3	146	56.3	188.8	53.1	19.4	0.4	72.8
Niger	17	4.5	1.7	26.3	7.6	2.6	–	10.3
Nigeria	41.4	128.2	64.3	310.1	93.9	30.8	30.8	155.5
Tanzania	16.9	16.2	7.7	95.6	32	7	6.6	45.6
Uganda	3.2	1.2	0.7	37.5	11.5	8.3	1	20.7
Average	35.2	56.9	26	123.2	36.9	15.1	9.7	58.4

is also problematic unless nitrogen-use efficiency (NUE), calculated as the rate between harvested N and input N in agricultural production, can be enhanced. Using data from 1961 to 2011 for 113 countries they find a pattern similar to the environmental Kuznets curve (EKC) where N pollution first increases and then decreases with economic growth in Western developed countries. They estimate the global NUE ratio to be 0.42 in 2010. Emerging economies such as China and India have not yet reached the EKC turning point as NUE is particularly low in China (0.25) and India (0.30) while it is much better in SSA (0.72) where N use is still low. Large parts of SSA still face an undersupply of N that prevents sustainable intensification. However, SSA has a strong need to increase yields to minimize area expansion and this should be achieved while retaining a relatively high NUE.

Micro data from Living Standard Measurement Survey (LSMS-ISA) data, compiled by Sheahan and Barrett (2014, 2017), are presented in Table 1. The LSMS-ISA data cover 22,000 households in the six countries. The Table shows average fertilizer nutrient rates per ha of cultivated land for cultivating households in these countries.

The data reveal that there are large cross-country variations and that incidence of use and nutrient use levels are quite high in some countries (Malawi, Nigeria, Ethiopia). Sheahan and Barrett (2014, 2017) also notice large within-country heterogeneity, especially in large countries like Ethiopia and Nigeria. Maize is the crop attracting most inputs, even more than cash crops. The data also reveal an inverse relationship between fertilizer use intensity and plot size as well as farm size. The inverse plot size-input use intensity relationship may partly be due to plot size measurement error but such measurement error should be fairly small in the LSMS data where plot sizes were measured with GPS (Carletto et al., 2013). The LSMS-ISA data also show that credit does not play an important role as a source of funding for accessing inputs, except in Ethiopia among these six countries. Less than one percent of the farm households used credit to obtain inputs. Sheahan and Barrett found that national-level factors explained nearly half of the variation in inorganic fertilizer use demonstrating the critical importance of national-level policies and institutions to facilitate sustainable intensification.

It is challenging to identify policies that can cost-effectively stimulate sustainable intensification and discourage area expansion while ensuring food security and poverty reduction. This requires a fundamental understanding of the decision environment of smallholder farm households that represent the large majority of land users in SSA. This requires a deep understanding of the production systems embedded in local agro-ecologies as well as market and institutional characteristics. This includes an understanding of what drives production, investment and consumption decisions of these land users.

3. An agronomic perspective and economic profitability

An agronomic understanding is important for assessing the potential for sustainable intensification of agriculture. Integrated Soil Fertility Management (ISFM) is an approach designed to obtain such an understanding and is defined as “a set of soil fertility management practices that necessarily include the use of fertilizer, organic inputs and improved germplasm, combined with the knowledge of how to adapt these practices to local conditions, aimed at maximizing agronomic use efficiency of the applied nutrients and improving crop productivity. All inputs need to be managed following sound agronomic principles” (Vanlauwe et al., 2010, 2015).

Conservation Agriculture (CA) is an another related approach to sustainable intensification that includes the three principles crop rotation/intercropping, permanent soil coverage, and minimum soil disturbance (Giller et al., 2009). CA can contribute to raise SOM and has been promoted in several SSA countries (Giller et al., 2015). CA has been seen as a solution to many of the problems in smallholder agriculture in SSA and its dissemination has received a lot of support from donors (Hobbs et al., 2008; Giller et al., 2009, 2015). While high adoption rates have been achieved in South-America and Australia in large scale mechanized agriculture, adoption rates have been disappointing among small-holders in SSA (Arslan et al., 2015; Giller et al., 2009, 2015), and this may be related to low short-term returns and high initial labor or cash costs to control weeds manually or by herbicides. Vanlauwe et al. (2014) argue that CA must be accompanied with a fourth principle in SSA, adequate use of inorganic fertilizers, to raise the production of organic matter and crop yields, as the amount of available organic matter otherwise will be too low for CA to function well.

An ISFM approach integrating fertilizer application with organic manure utilization and soil and water conservation may be a better approach to “tunnel through” the EKC and retain a high NUE (Zhang et al., 2015).

Large local heterogeneity in soils quality and nutrient content makes it more costly and difficult to fine-tune fertilizer supply and recommendations to local soil variation. Several studies have revealed that such heterogeneity may be large. E.g. Marenya and Barrett (2009) found that land degradation and poor soil quality are associated with low soil organic matter (SOM) content and this commonly limits the yield response to mineral fertilizer application. In their study in Western Kenya they found that about one-third of the plots in their survey had degraded soils that limited the marginal productivity of fertilizer use such that it became unprofitable at prevailing prices. The fact that poorer farmers are more likely to have such degraded plots can make it harder to stimulate fertilizer adoption without a complementary SOM package that is needed to enhance fertilizer use efficiency. A recent study be Bhargava et al. in Tanzania combines farm plot level LSMS-ISA data with biophysical remote sensing data on soil organic matter content from Africa Soil Information Service (AfSIS) and Land Degradation Surveillance Framework (LDSF). The study finds a strong positive correlation between soil carbon content and agricultural profitability. Fertilizer plays a limited role as it is used only on a small share of the land.

Suri (2011) used survey data from 1996 to 2004 in Kenya to study the marginal returns to improved maize and fertilizer technology adoption. She finds substantial heterogeneity in the returns. A small

share of the survey sample farmers have not adopted the technology even though returns are very high and this appeared to be due to supply constraints and poor infrastructure. A larger share of the sample had lower but positive returns but had adopted. A third group had about zero returns and switched in and out of the technology. Similarly, Liverpool-Tasie et al. (2017) uses LSMS-ISA data from Nigeria to study fertilizer use on maize in Nigeria where fertilizer use is already high (128 kg/ha, see Table 1). They find that the marginal physical product of N use to be quite low and therefore the expected profitability of N use also to be low for many farmers. High transportation cost for fertilizer is an important constraint to the profitability. Burke et al. (2017) also find higher fertilizer use rates to be marginally profitable or unprofitable in Zambia where soil acidity is an important constraint. Limited profitability evidently explains low fertilizer adoption rates in much of SSA.

4. Poor but efficient, too poor to be efficient, or predictably irrational?

Why is understanding farmers' economic behavior important in our context? Input use decisions are decentralized decisions by farmers that cannot be remote controlled. They can only be influenced by policies through information and economic incentives such as price signals and market access opportunities. They face fundamental production risks that may limit adoption of and intensity of use of risky inputs such as fertilizer.

Schultz argued that small farmers are poor because of resource and market constraints and not because of their own in-efficiency. The 'poor but efficient' view of small farmers has been a dominant paradigm in development economics. The idea about 'poverty traps' has more recently gained popularity (Sachs et al., 2004; Carter and Barrett, 2006) and has been an important basis for expanding development aid and support to agriculture in SSA, including support to input subsidies.

A poverty-population-environment trap is another narrative that builds on Malthus (1798) and is combined with studies on natural resource management and degradation. This narrative brings us closer to the role of soil nutrients, nutrient mining, soil degradation and incentives for conservation and fertilizer use that are central issues here (Shiferaw and Holden, 1998; Barbier, 2010). The recent review by Barrett and Bevis (2015) provides additional evidence on the self-reinforcing feedback between low soil fertility and chronic poverty.

A fundamental question is how rational smallholder farmers in Africa are? Is there a need to question the poor but efficient hypothesis and the widely used Expected Utility Theory (EUT) and Samuelson's discounted utility model as the basis for predicting individual and household decision-making such as technology adoption and input use? Deviations in behavior from what these models predict imply in-efficiencies and time inconsistent behavior. Experiments in behavioral economics have demonstrated a lot of deviations from the standard rational agent model, see DellaVigna (2009) for an overview based on field evidence. Such deviations are also likely to be widespread among smallholder farmers in SSA. For this paper, it is intertemporal choice and choice under risk (uncertainty) that are the most relevant decisions to focus on.[1]

4.1. Intertemporal choice

Time-inconsistent behavior such as present bias and hyperbolic discounting are widespread phenomena and may explain low input use and underinvestment in profitable activities. However, poverty and liquidity constraints may also explain high private discount rates among smallholders and low investment levels and land degradation (Holden et al., 1998; Shiferaw and Holden, 1998). These phenomena may represent Pareto-relevant externalities (in-efficiencies) that merit intervention. Hyperbolic and quasi-hyperbolic[2] models of behavior in intertemporal choice have been found to robustly predict inter-temporal decisions over varying time horizons (Holden and Quiggin, 2017b). Liquidity and credit constraints may lead to similar effects. However, it is not obvious what the optimal intervention design is to internalize this type of externality and whether the benefit of the intervention would be higher than the cost (a necessary requirement for these forms of externality to be Pareto-relevant).

Duflo et al. (2011) proposed to use nudging to stimulate fertilizer use by farmers based on experimental evidence from Kenya. Based on their finding that farmers underinvested in fertilizer even though fertilizer use was highly profitable, they designed an experiment where fertilizer was offered at harvest time rather than at planting time and found that this may be a low-cost approach to enhancing fertilizer use and to be better than offering subsidized fertilizer at planting time. Farmers appeared to be unable to hold on to cash from harvest time when they sold their crops and until planting time when they usually bought their inputs. A simple nudge intervention could therefore represent a win-win solution that would enhance input use without high subsidy costs. Holden and Lunduka (2013b) investigated the potential of this approach of offering inputs at harvesting time rather than at planting time with a framed field experiment in Malawi. They found the potential of the approach to be less encouraging there as maize output prices were found to be very low at harvest time and to have almost doubled by planting time. Selling maize at harvest time to buy fertilizer then would give them much less fertilizer than if they waited with selling their maize until planting time. Fertilizer prices do not show similar seasonal price fluctuations.

Clot and Stanton (2014) studied time preferences and willingness to participate in a Payment for Environmental Services (PES) program in Uganda and found that present biased time preferences were positively associated with participation in PES.

4.2. Risk preferences

The seminal experiments of Binswanger (1981) on behavior under risk in India revealed that farmers are risk averse but it also revealed some anomalies that are not consistent with EUT, e.g. partial asset integration, different responses to downside than upside risk and responses to luck in previous rounds of the experiment. Wik et al. (2004) use the Binswanger approach and find similar results in Zambia. Rabin (2000) has further demonstrated that risk aversion in small gambles should imply extreme risk aversion in large gambles. It is rational to be risk neutral in small gambles but this is not how most people/smallholder farmers behave.

Reference dependent utility,[3] with prospect theory as a special case, may therefore be better theoretical models of actual behavior in relation to risk and uncertainty than EUT (Kőszegi and Rabin, 2007). EUT, which serves as the rational choice model for decisions under risk, implies linear weighting of probabilities. EUT incorporates standard risk aversion due to the concavity of utility functions. Risk aversion and

[1] For simplicity the distinction between risk and uncertainty is dropped and so are some other important behavioral issues such as optimism bias/overconfidence, the distinction between stationarity and time consistency, endowment effects in relation to in-kind versus cash transfers and other regarding preferences. These probably play a less important role in relation to individual input use.

[2] Hyperbolic and quasi-hyperbolic responses are forms of systematic time-inconsistent responses that imply that discount rates are inversely related with the time horizon of the alternative choices. Quasi-hyperbolic discounting is due to present bias, which implies a strong preference for immediate consumption.

[3] Recent research in economics has revealed that it is common to anchor utility to some reference point such as past income, the income or welfare level of neighbors or other peers, while EUT ignores such anchoring. Prospect theory uses status quo as the anchor and separates utility above and below status quo.

uninsured risk may be one reason for low input use as fertilizer use is risky. Subjective probability weighting is another widely found phenomenon and most people over-weight low probabilities and underweight high probabilities (Wakker, 2010). Non-linear weighting of probability is associated with rationality failure (Tversky and Wakker, 1995). There is evidence that this phenomenon is associated with literacy and numeracy levels and may thus be a bigger problem in developing countries (Dohmen et al., 2010; Reyna et al., 2009). Loss aversion is the third phenomenon that is associated with prospect theory and the fact that marginal utility of a loss is higher in absolute terms than the marginal utility of a gain. Yet, there are few studies that have evaluated the relative importance of risk aversion, subjective probability weighting and loss aversion for input use among smallholder farmers in Africa. Holden and Quiggin (2017a) find that risk aversion and shock exposure are most important for maize variety choice and Holden and Quiggin (2018) find that subjective probability weighting in the form of over-weighing of low probability of low returns is negatively associated with the intensity of fertilizer use in Malawi. A new study in Ethiopia indicates that farm households are less risk averse than found by earlier studies and indicates that earlier studies, including that of Binswanger, may suffer from measurement error and this may have resulted in biased estimates of risk aversion (Vieider et al., 2018).

The inter-relationship between risk and time preferences has recently been subject to intensive research and controversies on methodological grounds (Andersen et al., 2008; Andreoni and Sprenger, 2012, 2015). Andersen et al. (2008) showed that ignorance of risk aversion in the estimation of time preferences may have caused an overestimation of discount rates. When comparing larger future amounts with smaller current or near future amounts they correct for diminishing marginal utility of the amounts based on Multiple Price List risk preference experiments. Andreoni and Sprenger (2012, 2015) contest this approach using an alternative Convex Time Budgets approach allowing intermediate combinations of near future and far future amounts. They find lower levels of risk aversion, higher discount rates and no present bias. Clot et al. (2017) find that impatience is associated with higher risk aversion in a study in Uganda.

Most large surveys such as the LSMS-ISA do not collect data on preferences and we thus have to rely on smaller samples that combine detailed farm household data with the relevant behavioral experiments. More research is needed to explore the behavioral heterogeneity of smallholder farmers and its implications for policy.

5. A review of selected policies

I focus on two policy approaches (fertilizer subsidies and productive safety nets) that have been controversial and subject to recent research and testing based on the argument that these two approaches need to be integrated in smarter future policy designs to facilitate sustainable intensification in SSA.

5.1. Fertilizer subsidy programs

While many economists have argued strongly against use of subsidies to promote input use except for overcoming short-term knowledge/familiarity constraints, input subsidies regained popularity among policy-makers in many African countries after the apparent success of Malawi in particular with its targeted input subsidy program in the period 2006–2010. The spending on input subsidy programs in ten African countries ranges from $0.6 to $1.0 billion per year or 14% to 26% of public expenditures on agriculture (Jayne et al., 2018). The relative success of fertilizer subsidy programs has for this reason also attracted a lot of interest among researchers and only a brief summary can be provided here of the findings in this literature.

The urgency of food insecurity issues and high priority to short-term effects and political support/popularity may have caused a bias towards use of input subsidies rather than long-term investments in infrastructure, research and technology development. The argument has been that it is cheaper to import fertilizer than to import food to meet the food needs of the food insecure. If this were a temporary solution to a drought or some other shock, that created temporary food shortages, such a subsidy may be defended, but as a permanent solution to a food insecurity problem, it could create dependency on subsidies and hinder other forms of adaptation to reduce food insecurity. This would drain resources that could otherwise have been invested in sustainable intensification and rural transformation that would enhance food security in the longer run.

Economists use the identification of market failures as a basis for identifying the need for interventions. The non-existence of markets may not imply a market failure, however. The cost of establishing a market where it does not exist may be higher than the benefits obtained from its establishment. Pervasive characteristics of many SSA rural economies such as immobility of land, low population densities in remote rural areas, seasonality in rain-fed agriculture, covariate risk, and moral hazard in human behavior result in pervasive market imperfections for which there are no quick fix solutions (Binswanger and Rosenzweig, 1986). I prefer the concept of market imperfection to characterize non-perfect markets, including missing market situations, and reserve the concept market failure to situations where one can be sure that the cost of intervention to improve the market is lower than the benefit from the intervention. Only in such a situation would it also be a policy failure not to intervene to eliminate the market failure. This implies e.g. that an intervention to establish a credit market where it does not exist may be a policy failure as it does not eliminate the market failure. Forcing or stimulating people to take credit in a risky environment may make them even more vulnerable if exposed to bad states of nature. This is especially true in environments with covariate risk and with climate change possibly pushing towards hotter and wilder weather conditions.

The Starter-Pack input subsidy program was introduced in Malawi after the input credit program collapsed in the early-mid 1990s. It is not obvious that a new input credit program should replace the current Farm Input Subsidy Program (FISP) in Malawi. FISP has become an expensive undertaking for the Malawian government while still in high demand locally. While Malawi has become one of the SSA countries with highest fertilizer use intensities in its smallholder agriculture, the majority of smallholders are still net buyers of maize, their main staple crop to which most of the fertilizer is applied. The financial constraints the country faces has forced a scaling-down of the subsidy program and the future of the program is under debate. So what has been learnt from the impact studies of fertilizer subsidy programs in Malawi and other SSA countries to date?

Ricker-Gilbert et al. (2011), using data from Malawi for the period after the targeted subsidy program was scaled up, found that access to subsidized fertilizer was associated with a substantial crowding out of demand for commercial fertilizer. Similar crowding out effects have also been found in Zambia by Xu et al. (2009) and Mason and Jayne (2013), and in Nigeria by Takeshima and Nkonya (2014). A reason for a relatively strong crowding out effect in Malawi could be targeting errors. Although the program officially aimed to target resource poor smallholders, targeting errors are widespread. They are related to local power structures such that wealthier farmers who would have afforded to purchase commercial fertilizer, also managed to access substantial quantities of subsidized fertilizer directly through the program or indirectly through leakages from the program (Holden and Lunduka, 2013a; Mason and Jayne, 2013).

In remote locations, and where fertilizer use is a new thing, there may also be crowding in effects due to learning and networking effects from introducing fertilizers through input subsidies. This has been found in an experimental study in Mozambique (Carter et al., 2014). The crowding-out effect is likely to be lower if the subsidy helps households overcome liquidity constraints that otherwise would

constraint fertilizer purchases at commercial price. Holden and Lunduka (2013b), combining a household survey and a framed field experiment, find evidence of high demand for fertilizer in Malawi and that liquidity constraints contribute to sub-optimal effective demand.

There are fewer studies of the general equilibrium and longer-term impacts of fertilizer subsidies. Holden et al. (2005b) used a micro-meso-level computable general equilibrium model for a surplus grain producing area in Ethiopia and found that an output tax ploughed back as a fertilizer subsidy both reduce the land degradation externality and reduce poverty. Arndt et al. (2015) used an economy-wide model for Malawi to estimate the impacts of the FISP there. They found that when taking the indirect effects of the program into account the benefit-cost ratios of the program increase by 60% compared to partial equilibrium calculations. They find the program to be pro-poor and create double dividends through higher and more drought-resilient yields.

The threat of climate change looming behind has also triggered more focus towards the need to develop drought resilient crops and farming systems. One of the developments has been more Drought Tolerant (DT) maize varieties being disseminated in a number of SSA countries such as in Malawi where the take-up has been most rapid. Recent research shows that this is partly because of the dissemination of free seeds through the input subsidy program (Holden and Fisher, 2015). Holden and Quiggin (2017a) have shown that the combination of access to DT maize seeds through the subsidy program and exposure to droughts has enhanced DT maize adoption and even more so among risk averse farmers. Holden and Quiggin (2018) show that "probabilistic risk aversion", implying that the majority of farmers overweight the probability of bad weather outcomes, result in lower use of risk-increasing inputs such as fertilizer on risky crop varieties. They find that DT maize, which is less risk-increasing in this sense than other improved maize varieties, is less prone to this problem. The dissemination of DT maize varieties thus also enhances fertilizer use intensity.

5.2. Productive safety net programs

The productive safety net policy program (PSNP) has been a primary tool to enhance food security in Ethiopia since 2005. While the Food-for-work (FFW) approach had been used widely in the country also before that, the PSNP identified chronically food insecure communities and households that were entitled as participants of the program for a five years period, which later was extended for another five years for households not yet ready for "graduation" from the program. The program may only indirectly affect input use through its insurance effect, cash and/or food supply effect, and the investment in pubic goods effect. Much of the labor mobilized through the program has gone into investments in soil and water conservation and may for that reason have long-term productivity and sustainability effects. There exists evidence that FFW and PSNP can increase the probability of using chemical fertilizers and the extent of their use (Bezu and Holden, 2008; Gilligan et al., 2009; Hoddinott et al., 2012; Villegas et al., 2016). One should expect NUE to be enhanced on conserved land and this should also enhance the returns to fertilizer use but further research is needed to investigate and estimate these effects.

6. A need for smarter interventions

Economists have typically argued for incentive-based rather than command-and-control policies also in the environmental conservation area. In reality, it is an empirical question whether the price-based, law-based policy, or a combination of these is optimal from society's perspective.

One of the challenges of subsidies and taxes is that they often lead to quite complex substitution-, crowding in and crowding out effects at the micro-level and to general equilibrium and dynamic effects if scaled up. This is particularly complex when efficiency, equity, sustainability and political feasibility issues are closely inter-related such as in our case. These complexities make it hard to predict the overall outcomes of subsidies or taxes.

While the World Bank World Development Report 2008 was positive about the idea "smart subsidies", the issue of nutrient depletion and enhancement of NUE has not caught much attention in relation to the new fertilizer subsidy programs where the targeting has rather been focused on poverty and food security.

Nutrient mining will undermine long-term land productivity and may be seen as an environmental externality. Economists use the ideas of Pigou (1960) to argue for the use of Pigouvian taxes to internalize (=remove) such negative externalities. However, imposing taxes on poor land users may possibly even lead to more land degradation. Pigou argues that subsidies may be used in cases where there are economies of scale. Stimulation of technology adoption is another argument used and that I already have discussed related to fertilizer subsidies. If too little use of fertilizer leads to nutrient mining and falling land productivity, and a subsidy on fertilizer would boost fertilizer use and lead to more sustainable food production, introducing such a Pigouvian subsidy may be defended. But this is an empirical question requiring careful assessment of all costs and benefits. Various modelling studies have indicated that such a policy may work in certain contexts (Holden et al., 2005a).

There is, however, a risk that fertilizers become a substitute for conservation in a nutrient deficient environment and it is therefore important to link such as subsidy to a conservation requirement ("interlinkage policy") (Holden and Binswanger, 1998; Holden et al., 2005b). This may imply a combination of a command-and-control and an incentive-based policy and it will require strong local institutions for targeting and enforcement. The Productive Safety Net Program (PSNP) in Ethiopia is unique in the sense that it has aimed to "kill several birds with one policy tool". Elements of this policy are similar to Payment for Environmental Services (PES) as a policy to internalize environmental externalities based on a combination of beneficiary-pays and a polluter-pays principle (Engel et al., 2008). Wunder (2005) defines PES as (a) a voluntary transaction where (b) a well-defined environmental service (or a land use likely to secure that service) (c) is being 'bought' by a (minimum one) service buyer (d) from a (minimum one) service provider (e) if and only if the service provider secures service provision (conditionality). This approach is more relevant in settings where environmental service (ES) providers are poor, marginalized landholders or powerful groups of actors who also have to contribute themselves (conditionality requirements). The Ethiopian PSNP is combined with a "labor tax" in form of a compulsory labor provision for investment in local public goods that is a requirement in order to benefit from the compensated activities, such as food-for-work or cash-for-work. These investments in local public goods such as land conservation, tree planting, irrigation investments, road construction, etc., have stronger long-term effects than input subsidies typically will have. Proper implementation makes this a smart PES approach where local beneficiaries share the costs. The costs of the compensations have been paid by the government and international organizations like the World Food Program and the World Bank (Trust Fund). The program and approach may make for an interesting study whether it can serve as a way to "tunnel through" the ECK.

Antle and Stoorvogel (2008) use simulation models to assess the potential of PES for carbon sequestration in Kenya. They assume that farmers adopt carbon contracts that require them to use minimum 600 kg/ha organic manure and 60 kg/ha inorganic fertilizer in addition to incorporating crop residues on the plots. The adoption of such contracts obviously depends on the price of carbon, price of fertilizer, other inputs and output, the functioning of the input market, cash availability, and so on. Their analysis for Machakos district in Kenya indicates that fertilizer use is profitable and that low fertilizer use is due to market access and/or cash constraints. Social costs and benefits also depend on the administrative costs and targeting efficiency of such a

program. More research with a RCT piloting approach is needed to explore this in different contexts.

7. Conclusions

SSA faces massive challenges to meet the food needs of its rapidly growing population and the broader Sustainable Development Goals towards 2050. Sustainable intensification of agriculture and rapid economic transformation while also reducing population growth rates will be necessary to protect remaining forest areas.

No silver bullet policies exist to achieve this but promising new policies need to be pilot tested in heterogeneous environments before scaling up, drawing on the improved toolbox of researchers in concerted action with SDG oriented policy-makers. The challenge is to create incentives for sustainable intensification to reduce area expansion and deforestation by stimulating nutrient demand while retaining nutrient use efficiency. This is easier said than done, but may not be impossible.

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